On the Correction for Personality required by the Observations of the Moon made with the Greenwich Transit-Circle.

By E. Neison, Esq.

During the course of my investigation of the corrections required by the theory embodied in Hansen's Lunar Tables in order to bring the tabular place of the Moon into accord with observation, I have most carefully compared the corrected theory with the observations of the Moon made with the Greenwich Transit-Circle. The result of the comparison is decidedly satisfactory when the error of the Moon's mean longitude is deduced separately for each year, showing that the theory of the terms of short period has been rendered accurate. It remains to compare the errors of mean longitude deduced for each year from the observations, with the view of deducing the requisite corrections to the theory of the terms of long period. This portion of the investigation has not yet been completed, though the discordance between theory and observation has been already materially reduced by the introduction of several terms of long period, whose existence has been discovered by my theoretical researches. During this part of the investigation I have discovered several sudden changes in the error of mean longitude, which were too sudden to arise from any defect in the theory, and too large and too marked to be merely accidental. Lately, by a rigorous examination of the observations, I have convinced myself that these sudden changes do not arise from any imperfections in the theory, but must arise from some cause within the Observatory itself.

The observations of the Moon with the Transit-Circle at Greenwich appear to be, as far as possible, equally divided amongst four of the Assistants, though occasionally observations are made by others. As a rule, however, about five-sixths of the total number of observations are made by four of the Assistants. It might therefore be very fairly assumed that the mean of the observations made by these four observers would be to all intents independent of any systematic error due to personality on their part, as it is known that such personality is not large in any one case. Therefore, so far as I am aware, hitherto everyone who has investigated the theory of the Moon has assumed that the error of mean longitude derived from a year's observation might be held to be independent of any personality on the part of the observers, and to be comparable with the error deduced from the observations of any other year.

Some time back it was suggested to me that the personal error of the Greenwich observers might not be constant, and that therefore the mean error derived from their observations might vary from year to year. From some notes I had of a paper by

Mr. Dunkin, entitled 'On Personality in observing Transits of the Limbs of the Moon" (*Monthly Notices*, 1869, vol. xxix. page 259), I was aware that the personal equations of the lunar observers were tolerably constant and in no case large, so that it did not seem likely that any such variation would occur. To satisfy myself that this view was correct, I compared the mean of all the observers for each year with the mean for the entire period of six years, using the data given in my notes of Mr. Dunkin's paper. The result was entirely satisfactory, the corrections to be applied to each year's observation to reduce them to the same standard being as under:—

		s
1863	=	−0·010
1864	=	+0·003
1865	=	−0·010
1866	=	+0·010
1867	=	0·000
1868	=	+0·008

These quantities were smaller than the probable error of their determination, and were themselves so small that they could be neglected.

When, therefore, my investigations showed that these variations, or rather sudden changes, in the error of mean longitude were probably due to some cause within the Observatory itself, it was difficult to imagine what could be the real source of these variations. There had been no change in the method of reduction, so that it could not arise from that cause. Further investigation showed that the observations with the altazimuth were affected by the same sudden changes, though to a modified amount; it was evident, therefore, that the origin of these changes was not in the instrument itself. Everything pointed to its arising from some effect of the personality on the part of the observers. Yet this conclusion seemed negatived by the results already referred to, which I had obtained some years previously. I resolved, however, to investigate anew this question.

I knew that in his paper in the xxix. volume of the *Monthly Notices*, Mr. Dunkin had arrived at the conclusion that observers had a very different personal equation for each limb of the Moon, but that for each limb this personal equation was almost constant. My first step was, therefore, to examine Mr. Dunkin's paper to see what light it might throw on this subject. It appeared that Mr. Dunkin had based his investigation on the assumption (*loc. cit.* page 263) that "the mean tabular errors are assumed to be constant throughout the mean lunation." It is now known that this assumption is not a permissible one, for the tabular

errors are not constant throughout the mean lunation; but that, owing to imperfections in the theory, they are systematically different before and after Full Moon. My own investigations have shown that this error varies during the year to such an extent that the difference in the Moon's tabular error before and after opposition will vary from nearly 8″ in one part of the year to less than 1″ in another part. For this reason, therefore, the conclusions which have been arrived at by Mr. Dunkin in his paper will require material modification.

The data which has served as the basis of my investigation has been the Greenwich Transit-Circle observations of the Moon made during the fourteen years between 1863 and 1876. Each Assistant's observations were separately extracted from the different volumes of *Greenwich Astronomical Results* and discussed by themselves, the observations of the I and II limbs being kept separate. As far as possible without separately calculating the corrections for each observation, the main errors of short period in the theory were eliminated, and it was assumed that the smaller errors would practically destroy each other in the mean result. Next, the results obtained for each observer were referred to one observer, who was taken as the standard. For this purpose Mr. Criswick was selected, for the reason that his observations alone extended throughout the entire period of fourteen years. Fortunately it also happens that his observations are the most numerous.

In this manner an approximate value of the personal equation of each observer was obtained for each year. The results were perfectly analogous to the similar results given by Mr. Dunkin, in his paper already quoted, and they clearly showed that, not only was the personal equation of each observer small, but that it was nearly constant in each case. Much of the deviation from the mean could be traced to the effect of the errors in the theory which had been left to correct themselves. The result for each year was weighted in proportion to the number of observations on which it rested, some slight weight being also given to the equable distribution of the observations. Then, from the different results for each of the fourteen years, the following values were obtained for the mean personal equation of the observers:—

		For I Limb.		For II Limb.	
		s	Weight.	s	Weight.
Dunkin	− Criswick = D − C =	−0·012	4	−0·032	3
Ellis	− Criswick = E − C =	−0·106	9	−0·065	7
J. Carpenter	− Criswick = JC − C =	−0·125	8	−0·038	6
Lynn	− Criswick = L − C =	+0·034	4	+0·058	3
A. Downing	− Criswick = AD − C =	+0·007	2	+0·109	2
Thackeray	− Criswick = T − C =	+0·040	1	+0·093	½

Substituting these values in the original expressions, it was found that they well satisfied them, the residuals being reduced to small quantities, in the greater number of cases less than $^{s}\cdot 020$.

The next step is to refer all the observations to some standard which will be more independent of the variations due to the imperfect elimination of the errors of the lunar tables and the chance errors of observation than can be the case with the mean of the observations which any selected observer may make in a year. It is evident that, by merely referring the results to the mean of the observations obtained by the selected observer in the year, the entire deviation of that mean from the true value of the personal equation of the observer is thrown on all the values for the personal equations of the other observers as determined from the observations of the year, creating in them merely fictitious variations. If it were possible to determine the absolute personal equation of Mr. Criswick, it would be possible to completely eliminate from the observations the effect of the personalities of the observers. This cannot be done from the Greenwich observations alone. Some standard must be assumed, therefore, and it is immaterial what standard be chosen in so far as the accuracy of the results is concerned. The most convenient standard would be to assume that the mean of all the personal equations of the seven observers is free from error. However, as the materials for determining the personal equation of two of the observers, Messrs. Downing and Thackeray, are very imperfect, it has been assumed that the sum of the personal equations of Messrs. Dunkin, Ellis, Criswick, J. Carpenter, and Lynn will be zero, and the mean of their observations correspond to the true place of the Moon.

The observations of each observer for each year were then referred to the mean error for the year derived from all the observations, so as to eliminate as far as possible the outstanding errors. The total number of observations was divided into four groups, 1863–69; 1870–72; 1873–74; 1875–76; in each of which the main observations of the Moon were made by four Assistants. Each of these groups was marked out from the others by the fact that in it the place of one of the observers of the preceding or following group was taken by another observer. It was then assumed that each of these groups needed a correction, a_1 a_2 a_3 a_4 respectively, to bring the mean of the observations in the group into accord with the selected standard. Then these corrections were determined by equating the mean results of the three observers who observed in both groups, after correcting each for proper personal equation.

In this manner the following values were obtained for the personal equations of the different observers for each limb of the Moon. The probable errors were obtained from the residuals.

	I Limb.		II Limb.	
	s	s	s	s
Dunkin =	+0·025	±0·012	+0·004	±0·014
Ellis =	−0·060	±0·009	−0·041	±0·010
Criswick =	+0·045	±0·008	+0·026	±0·009
J. Carpenter =	−0·074	±0·010	−0·014	±0·012
Lynn =	+0·075	±0·015	+0·066	±0·020
A. Downing =	+0·006	±0·022	+0·132	±0·026
Thackeray =	+0·063	±0·025	+0·183	±0·050

These personal equations are unmistakably real, as is clearly shown by the small probable errors, which show how small are the outstanding residuals which they leave. Where the same four observers have been engaged, and where there can be no uncertainty as to the values of the quantities a_1, a_2, a_3, a_4 to interfere with the accuracy of the results, the differences between the mean of all observers and the mean of each are remarkably constant and uniform, showing clearly that they are due to real personal equations, and not merely to outstanding errors. Moreover, these personal equations are quantities whose variations must be due either to purely accidental errors which may have remained uneliminated, or to a real change in the personal equation of the observer. There seems little indication of the presence of any real change. Therefore the variations are presumably accidental, and of the nature to which may be most safely applied the theory of probable errors.

Owing to the much smaller number of observations, and the shorter period over which they extend, there must be a considerable uncertainty as to the accuracy of the values which have been assigned to the personal equations of Messrs. Downing and Thackeray, and especially of the latter. This will, of course, disappear to all probability when the investigation can be extended to the observations which have been made during the years 1877, 1878, and 1879. I believe, however, that the true values of the personal equations of these observers will be found to be included within the limits of the probable errors assigned to them.

The consideration of these personal equations leads to a very important result. Of the four observers—Messrs. Dunkin, Ellis, J. Carpenter, and Criswick—who observed the Moon from 1863 to the end of 1869, no less than three of them—the three first—were replaced by other observers during the five years 1870–74. But whereas the three retiring observers had personal equations whose mean value was largely negative, they have been succeeded by three observers whose personal equations are all largely positive. This change of observers has therefore introduced a considerable increase in the mean tabular error of the Moon which has no real existence. Each replacement of one observer by

another—a change which has practically come into operation at the beginning of a year—has been accompanied by a sudden increase in the tabular error of the Moon, an increase which has no foundation in fact. Before, therefore, the errors in the Moon's mean longitude can be properly investigated from observation, it is necessary to remove these fictitious increases and reduce the entire series of observations to one systematic standard. From the values which have been determined for the personal equations of the seven observers, it is easy to calculate the correction which should be applied to each year to reduce the errors in the Moon's Right Ascension to a uniform standard. They are—

	I Limb.		II Limb.		Centre.	
	s	″	s	″	s	″
1863	+0·001 =	+0·015	−0·002 =	−0·030	0·000 =	0·000
1864	+0·017 =	+0·255	−0·003 =	−0·045	+0·009 =	+0·135
1865	+0·007 =	+0·105	−0·010 =	−0·150	0·000 =	0·000
1866	+0·016 =	+0·240	−0·006 =	−0·090	+0·007 =	+0·105
1867	+0·015 =	+0·225	−0·009 =	−0·135	+0·007 =	+0·105
1868	+0·020 =	+0·300	−0·008 =	−0·120	+0·008 =	+0·120
1869	+0·020 =	+0·300	−0·006 =	−0·090	+0·007 =	+0·105
1870	+0·013 =	+0·195	−0·012 =	−0·180	+0·002 =	+0·030
1871	−0·011 =	−0·165	−0·020 =	−0·300	−0·018 =	−0·270
1872	−0·004 =	−0·060	−0·017 =	−0·255	−0·009 =	−0·135
1873	−0·014 =	−0·210	−0·040 =	−0·600	−0·025 =	−0·375
1874	−0·005 =	−0·075	−0·054 =	−0·810	−0·029 =	−0·435
1875	−0·041 =	−0·615	−0·081 =	−1·215	−0·057 =	−0·855
1876	−0·047 =	−0·705	−0·079 =	−1·185	−0·058 =	−0·870

These results clearly show the unexpected effect of the change in the observers at Greenwich, there being a change of 1″ in the mean error of longitude in the short space of five years. The variation is of such unexpected magnitude, that it will be necessary to more rigidly examine the observation, correcting each individual observation for the errors of short period in the lunar theory, and taking into consideration the observations for the years 1877 and 1878. For this purpose, in my discussion of these observations, I shall have to introduce seven more undetermined coefficients to represent the personal equations of the seven Greenwich observers, and to be determined simultaneously with the errors in the mean longitude and coefficients of long period employed by Hansen in his Tables. In the meantime it appears to be important to make known the unexpected result of the present investigation.